Coastal Engineering Technical Note

APPLICATION OF SBEACH TO COASTAL PROJECTS

PURPOSE: To provide an overview and describe several engineering applications of the Storm-Induced BEAch CHange (SBEACH) model.

BACKGROUND: SBEACH is a numerical simulation model for predicting beach, berm, and dune erosion due to storm waves and water levels. Assumed in application of the model is that beach profile change during a storm event is dominated by cross-shore processes, and longshore transport effects on profile change are negligible. Application of the model is presently limited to profiles with non-cohesive sediments, with no exposed reefs or bedrock. The model does not account for variations in profile response due to localized longshore effects (e.g., in the vicinity of a groin) or interactions with tidal currents. SBEACH was developed and tested based on analysis of laboratory experiments conducted with prototype-scale wave heights and periods, together with physical considerations of profile evolution and coastal processes. The model was validated using field data on berm and dune erosion from four sites: CERC's Field Research Facility (FRF) at Duck, North Carolina; Manasquan and Point Pleasant Beach, New Jersey; and Torrey Pines Beach, California. The model was shown to represent the erosional phase of a storm event satisfactorily, while predicted profile recovery was only qualitatively in agreement with measured data. Because of a lack of data quantifying dune overwash processes, this first version of SBEACH did not simulate dune overwash.

Additional testing and refinement were conducted in applications of the model to the Ocean City, Maryland beach fill project, using data from the 1991 "Halloween" storm, and two Northeasters (Kraus and Wise 1993, Wise and Kraus 1993). This data set included excellent information describing dune response to high waves and water levels; and, based on simulations at Ocean City with multiple profile lines and sequential storms, an overwash algorithm was developed and tested. The algorithm improved calculation of measured dune and foreshore profile response at Ocean City. SBEACH Version 2.0 was released including the overwash algorithm.

Detailed information on model formulation and development may be found in SBEACH Reports 1 and 2 (Larson and Kraus 1989a; Larson, Kraus, and Byrnes 1990). SBEACH Version 2.0 is available for use on personal computer (PC), documented in Report 3 (Rosati et al. 1993), and within the mainframe computer-based Coastal Modeling System (CMS) (Cialone et al. 1991).

INPUT DATA REQUIREMENTS: SBEACH requires five types of input data: initial beach profile, median grain size representative of the active profile, water elevation (time series or constant value), wave height and period (time series or constant values), and values of model calibration parameters. If the model is being calibrated, a post-storm measured profile is also required for comparison with predictions. Three types of additional data may be input to further represent the beach configuration and forcing conditions: shoreward boundary condition (e.g., seawall), time series of wave direction, and time series of wind speed and direction. If wave direction is not specified, normal incidence is assumed; if wind data are not specified, the default is no wind action. In addition, a beach fill option allows the fill cross-section to be defined with up to 10 points. For a seawall or revetment, the cross-shore location, whether failure is allowed, and failure criteria may be specified.

Depending on the type of project analysis required, and data availability, SBEACH applications may range from a limited effort (scoping mode), to an extensive study (design mode). The scoping mode uses minimal data input to provide qualitative results under simplified conditions, appropriate for a reconnaissance-level study or to identify possible project alternatives. The design mode is a rigorous application of the model in which all available data and knowledge about the project site are applied for model setup, calibration, and verification; evaluation of project alternatives; and design optimization. Data requirements are different for these two modes of application. As with any type of model application, the degree to which SBEACH predicts prototype profile evolution is dependent on the quality of the input data set, and level of application. Engineering judgement is required in interpreting model predictions.

Scoping mode. In the simplest application, SBEACH may be run with only one setup file, called the configuration file. Model calculation parameters may be set to default values, and constant wave height, period, angle, water elevation, wind speed and direction may be specified. A measured profile is not required, and the input beach profile can be defined schematically through the configuration file. Project alternatives, such as the addition of beach fill and/or a seawall, may easily be evaluated. If desired, any one or more of these input data types may be changed, and designated in additional input files to increase the detail of the scoping mode application.

Design mode. For detailed evaluation and optimization of project alternatives, SBEACH is ideally calibrated and verified prior to application. Calibration refers to the procedure of adjusting SBEACH calculation parameters such that the model reproduces the change in profile shape produced by an actual storm. Verification involves applying the calibrated model to reproduce profile change on the same beach for another storm, or to reproduce profile changes for the same storm but at different locations within the project area, using profiles with different cross-sectional shapes. For calibration and verification, representative profile data prior to and immediately following a storm event with known wave and water level conditions, as well as the beach characteristics, are required. Reproduction of profile change on the subaerial part of the beach, particularly the dune and berm, are usually emphasized for engineering purposes. Once the model is verified, design storm events may be run with the existing profile and various design alternatives to determine impacts and advantages of each.

In practice, ideal calibration and verification data are not always available. For these cases, calculation parameters used for a project with similar beach and storm characteristics may be adopted, model sensitivity to a range of calculation parameters may be assessed, and/or the default calibration parameters may be used. Predicted results should always be compared with available knowledge of site response to lend credibility.

MODEL OUTPUT: SBEACH produces four types of output data: simulated profiles (at intermediate time steps (if specified) and the final calculated profile); the cross-shore variation of several physical parameters (intermediate (if specified) and maximum wave height, intermediate (if specified) and maximum total water elevation and setup, maximum water depth, and volume change); a record of the various beach response and coastal processes that occurred during the simulation (accretion, erosion, overwash, boundary-limited runup, and/or inundation); and a report that reiterates input data as well as output parameters of interest. Parameters usually of interest in application of the model include maximum recession distances at user-specified elevation contours (up to three), and the landward-most occurrence of a user-specified erosion depth. Thus, the impacts of project alternatives on beach response (erosion, accretion, bar/trough formation, recession, etc.), wave height, water level, volume change, and the dune and/or upper beach (e.g., inundation, overwash) may be investigated with SBEACH.

PROJECT APPLICATIONS: SBEACH has been applied to coastal projects to: determine storm-induced beach response as a function of storm intensity for existing profile conditions; evaluate beach fill design alternatives; and, in conjunction with a site-specific runup and overtopping module, predict dune/seawall/revetment overtopping rates. SBEACH has also been applied in a research mode to synthetically evaluate the relative effects of various types of storms and beach fill designs (Kraus and Larson 1988; Larson and Kraus 1989b; Hansen and Byrnes 1991). Two of the coastal project applications, and two of the research applications are highlighted herein to illustrate capabilities of SBEACH for project design and evaluation. Concluding sections discuss recent model improvements in dune overwash predictions based on the Ocean City, Maryland data set, and ongoing cross-shore sediment transport research.

Panama City, Florida. SBEACH Version 1.0 was applied to this project to evaluate the cross-shore erosion and flooding protection provided by (a) existing condition profiles and (b) two beach fill design alternatives. The study area is located in the Florida panhandle on the shores of the northern Gulf of Mexico and extends 18.5 miles from the west jetty of the Panama City Harbor entrance channel to Phillips Inlet near the border of Bay and Walton counties. Storm-induced water level and wave height, period, and direction were numerically modeled for 55 storms representing historical or probable storm events. Beach profile response was then numerically modeled using four representative beach profiles, resulting in determination of beach recession, and wave height and water levels at the shore associated with each storm.

Wind-field, wave, and water-level models were used to hindcast a set of historical storms producing a time-series of storm surge water levels, wave height, and wave period throughout the duration of each event. As model input, data for Hurricane Eloise were used in calibration and verification at five locations. A sub-set of storms, which include the full range of conditions probable for the study site, was selected as the "training set." The training set of storms was used to drive SBEACH and compute profile recession. Maximum water level, wave height, and erosion at a particular contour were the storm response parameters used by the U.S. Army Engineer District, Mobile (SAM) to define economic damages. The statistical model HBOOT (Borgman et al. 1992; Scheffner, Borgman, and Mark 1993) was developed using the relationship of Gaussian Nearest-Neighbor Interpolation. HBOOT was used to determine the return periods for the various storm response (damage causing) parameters for all historical storms.

Two beach fill design alternatives were evaluated: a 9.1-m (30-ft) wide berm at 2.7-m (9-ft) NGVD elevation (Alternative 1); and a 21.3-m (70-ft) wide berm at 2.1-m (7-ft) NGVD elevation (Alternative 2). In general, Alternative 2 contained 20 to 25 percent more beach fill than Alternative 1, and extended the beach approximately 4.6 to 6.1 m (15 to 20 ft) further offshore. The as-designed beach fill profiles were "conditioned" to account for natural profile adjustment that could be expected due to normal wave action. Conditioning was achieved by performing a 1-month simulation using waves with a 5-second period and heights ranging from 0.25 to 0.75 m. Results from conditioning of the profiles indicated that the as-designed beach width will diminish due to readjustment of the beach fill material that occurs in response to typical wave action. Decreases in width may reach 50 percent at certain areas of the fill, as long as the volume of the beach fill is maintained. The adjusted fill material would continue to contribute to the effectiveness of the fill, as long as the volume of the beach fill is maintained. For a more detailed description of the Panama City, Florida project, the reader is directed to Farrar et al. (1994). Other studies applying SBEACH with similar scopes include: Glynn County, Georgia (Neilans et al. 1994); Folly Beach, South Carolina (Hales, Byrnes, and Neilans 1994); and Long Beach, New York (Rosati et al. 1994).

Revere Beach and Point of Pines, Massachusetts. SBEACH Version 2.0, in conjunction with other analyses and methodologies, was applied to this project to: (a) determine protection provided at Revere Beach by an existing coarse-grained beach fill, (b) evaluate coarse-grained beach and dune alternatives at Point of Pines (POP), and (c) predict volumes of water overtopping seawalls, revetments, and dunes due to storms of various intensities along the entire project reach. The project area consists of a crenulate-shaped bay shoreline, partially sheltered from wave attack by a large peninsula. Revere Beach comprises the majority of the project reach, and is backed by concrete seawalls of varying elevations fronted by a recently-placed coarse-grained beach fill. POP is at the downdrift end of the littoral cell, and is characterized by native beach material backed by low dunes of varying elevations. Between Revere and POP, a short native section of the shoreline is partially fronted by a rubblemound revetment and seawall.

Calibration and verification data were available for two profiles at Revere, and one at POP for the 1991 "Halloween" storm, which impacted the study area from 27 October through 1 November. Profile response at Revere indicated a uniform stripping of sediment during the storm, implying that longshore sediment transport processes in that portion of the study area were influential in beach response during the storm. This dominance of longshore transport precluded calibration and verification of SBEACH for the Revere Beach portion of the study reach. However, for calculation of overtopping volumes, SBEACH's wave transformation capabilities were deemed superior to other calculation methods planned by the U.S. Army Engineer New England Division, and SBEACH-calculated waves and water levels were used as input to other analyses to predict overtopping volumes. At POP, sediment was more nearly conserved between the pre- and post-Halloween storm profiles, thus allowing model calibration (Figure 1). Profile change as well as nearshore waves and water levels were predicted with SBEACH at POP. As part of the study, site-specific physical modeling tests of overtopping were conducted to provide information, in addition to that available in the literature, to develop a Runup and Overtopping Module (ROTM). The ROTM was applied in conjunction with SBEACH output to predict overtopping rates on profiles backed by seawalls, revetments, or dunes as a function of varying storm intensity. From 11 historical storms, a database of 50 synthetic storms was created, and used as input to SBEACH to predict profile evolution (at POP), and calculate overtopping rates (entire study reach).

The study concluded that the coarse-grained beach fill (0.49 mm median diameter) was highly effective in mitigating overtopping of the seawalls at Revere Beach, relative to the native beach condition (consisting of sediment with median diameter 0.21 mm). These results were substantiated by observations of beach response and overtopping with the existing coarse fill in place at Revere during the Halloween and December 1992 storms. Post-Halloween storm profiles at Revere used as input to SBEACH were predicted to maintain a high level of flood protection, even after the observed longshore loss of material. At POP, properly maintained dunes using the coarse fill material were predicted to provide the necessary level of flood protection, with even a higher level of protection than a revetment or revetment fronted by beach fill. The coarse fill provided more protection due to the erosive resistance of the fill material, and the increased elevation of the design dunes (relative to the design elevation of the revetment). Sensitivity testing indicated that grain sizes above 0.40 mm were significantly more resistant to erosive waves, as compared to native beach material. Similar results were found by Larson and Kraus (1989b) with eroded volumes decreasing significantly through the range of 0.2 to 0.4 mm, and decreasing less noticeably above 0.40 mm. For additional study findings, and more detailed presentation of study methodology, the reader is directed to Smith et al. (1994).

Research applications. Hansen and Byrnes (1991) applied SBEACH Version 1.0 using Ocean City, Maryland profile, beach, and storm data to evaluate the storm protection provided by four different types of beach fill design alternatives: (1) typical U.S. design, consisting of a flat berm extending from the base of a dune line or existing structure seaward, then tapering to the existing sea bed with a slope ranging from 1:10 to 1:30; (2) storm berm design, which is a berm with two levels, one of which is intended to be sacrificial for building an offshore bar during a storm; (3) profile nourishment, in which the fill is placed along the active profile from the berm crest to a depth offshore, as proposed by Bruun (1988); and (4) protective dune design, consisting of a large protective dune without a berm. They concluded that all designs withstood the impact of one northeaster or hurricane, but the subaerial volume change varied. Their results suggested that the best design for protection of the backshore area against storm impacts is a protective dune.

Kraus and Larson (1988) and Larson and Kraus (1989b) applied SBEACH Version 1.0 to two types of beach fills with equal volumes, a Bruun-type fill and an artificial berm. The profiles were subjected to a synthetic northeaster and hurricane of moderate intensity. The hurricane had a duration of 12 hr, with a peak surge of 2 m, and a duration above half the peak surge (1 m) of 6 hr. The northeaster surge had a duration of 36 hr, with a peak surge of 1 m, and a duration above half the peak surge (0.5 m) of 18 hr. The authors also varied grain size from 0.2 mm to 1.0 mm. Simulation results indicated that the hurricane and northeaster produced about the same amount of erosion, with a magnitude comparable to that observed on the mid-Atlantic coast for 2-5 year storms. Therefore, although the northeaster had a lower peak surge, its longer surge duration was approximately equal in erosion capacity to the higher surge of the shorter duration hurricane. They concluded that storm-induced beach and dune erosion cannot be uniquely specified through a single storm-related parameter

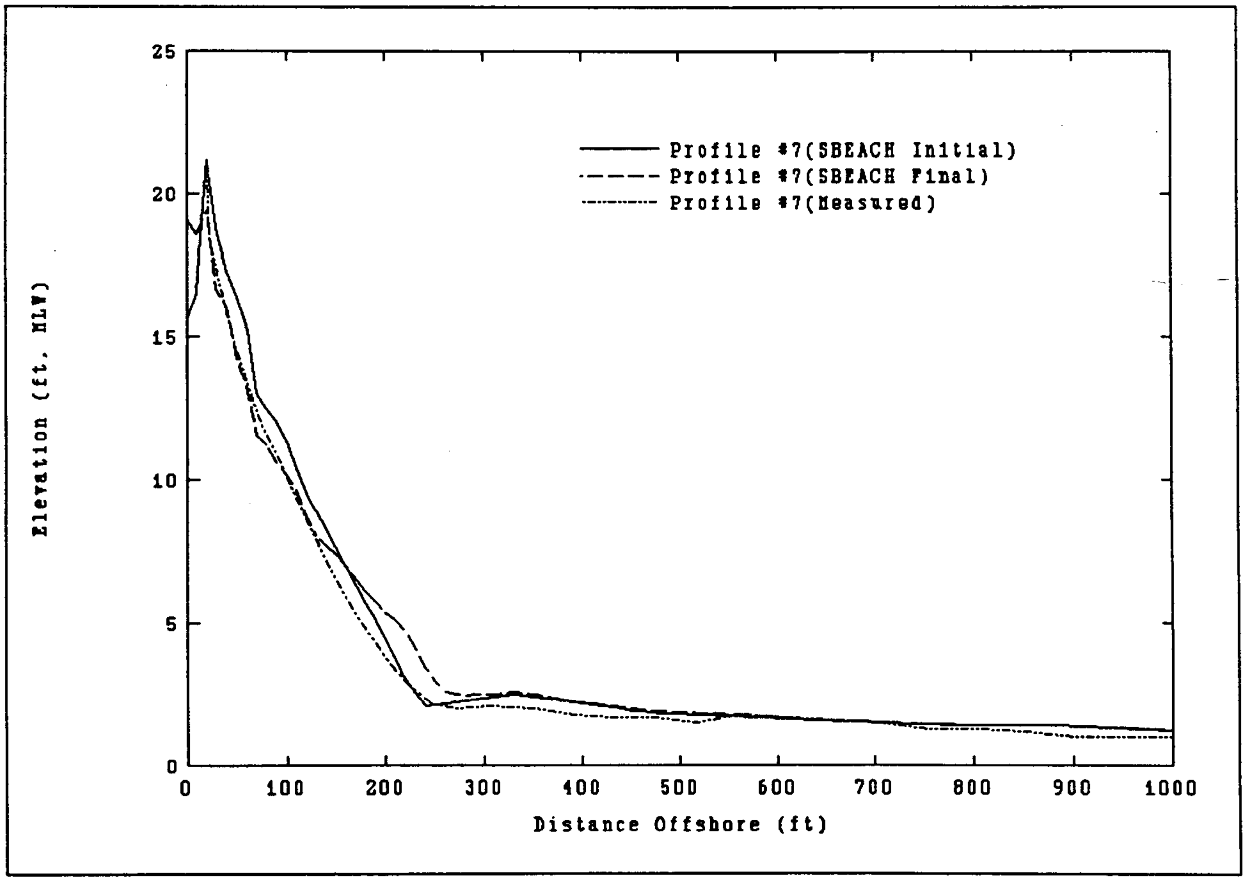

Figure 1. Measured and predicted profile response using calibrated SBEACH at POP with 1991 Halloween storm (from Smith et al. 1993)

such as the maximum surge elevation. Comparison of the two types of beach fills indicated that the Bruun fill experienced greater initial erosion during the early stages of wave action, but also greater recovery in the post-storm period. As mentioned in a previous section, the authors also found that eroded volume tended to decrease as grain size increased from 0.2 mm to 0.4 mm, with only slight decreases in the volume eroded for grain sizes from 0.4 mm to 1.0 mm. They concluded that it may not be cost-effective to use beach fill with a median grain size much greater than 0.4 mm, due to the typically greatly increased cost of larger sized material and declining benefit in decreased eroded volume.

Recent model improvements. Storm response data from the Ocean City, Maryland beach fill project were used to develop and test the overwash algorithm presently included in Version 2.0 of SBEACH. During January 2-5, 1992, a strong northeaster struck Ocean City, Maryland. As part of an emergency assessment of the beach fill project performance, numerical simulations of profile response to the storm were conducted using SBEACH. Post-storm profile measurements were not yet available at the time. Preliminary simulation results showed little erosion of the dune, whereas site inspections indicated that significant erosion had occurred, with the dune being totally removed at some locations. It was reasoned that the high waves and water levels associated with the storm caused significant dune overwash which was not being simulated by the model. Therefore SBEACH was modified to include an overwash algorithm, which produced results in qualitative agreement with site inspections. Figure 2 shows a comparison between the measured (pre- and post-storm) and predicted profiles at Ocean City, using SBEACH Version 1.0 (calculated without overwash algorithm) and Version 2.0 (calculated with overwash algorithm) with the January 2-5 northeaster storm data set.

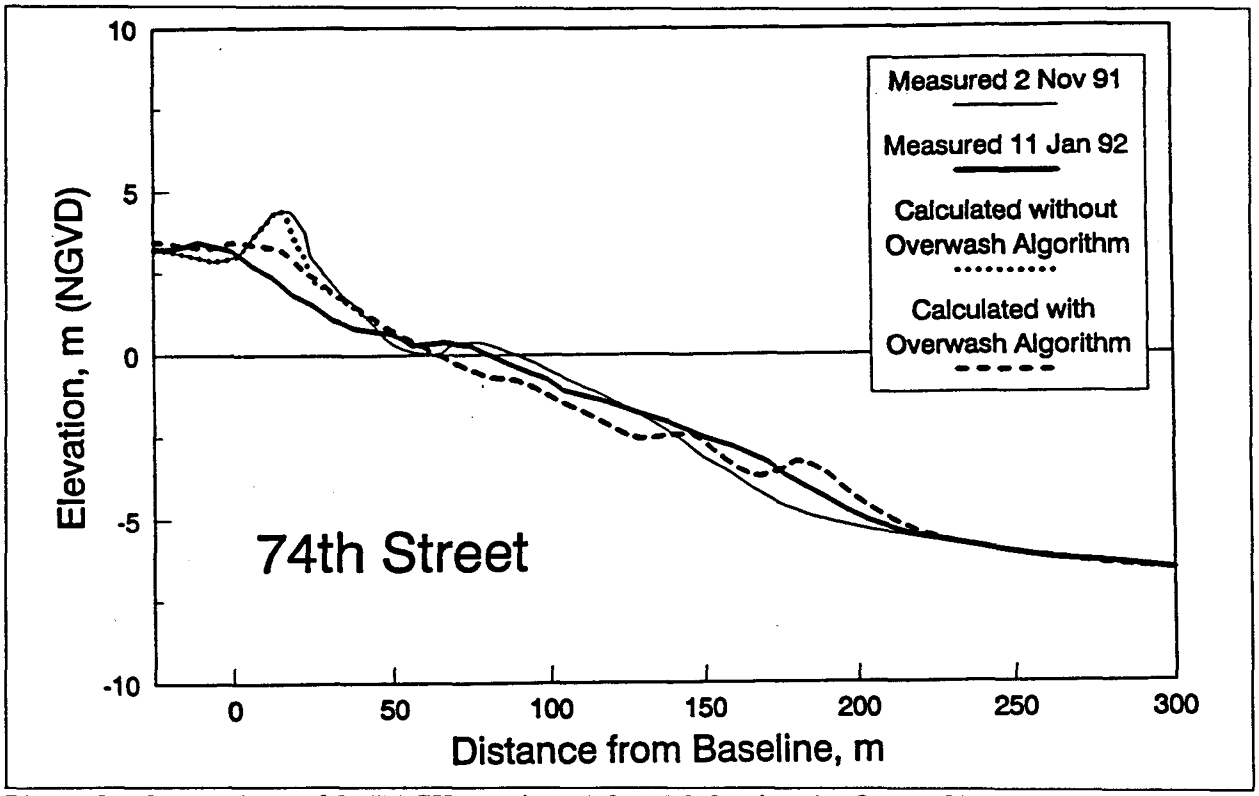

Figure 2. Comparison of SBEACH Versions 1.0 and 2.0 using the Ocean City, Maryland data set

Ongoing research. After Ocean City post-storm profile data were available for the January 2-5, 1992 storm, the overwash algorithm and relationships for foreshore erosion included in SBEACH were calibrated to the Ocean City data set, in a research application of the model. Results showed that the observed dune overwash and foreshore erosion were well reproduced (Kraus and Wise 1993). The research version of SBEACH, including the calibrated overwash algorithm and foreshore relationships, was further tested using additional profile lines and multiple storms, including the 1991 Halloween storm at Ocean City. Again, the calculated results well reproduced the measured dune and foreshore profile response (Wise and Kraus 1993).

Other ongoing cross-shore sediment transport research and development include analysis of the SUPERTANK cross-shore laboratory data set to improve predictions of profile change due to random wave attack. Improvements in random wave descriptions, overwash predictions, and an upgraded user interface will be incorporated in SBEACH Version 3.0, to be released in September 1994.

Storm-induced beach erosion of primary importance to Districts and Divisions occurs on the subaerial part of the profile, primarily in the dune and foreshore region. It is in these areas that the majority of storm damage benefits are realized. However, predictive expressions for sand transport and beach profile change in these regions are based on limited data sets. Additional research into foreshore and dune erosion processes is required to accurately predict the engineering quantities of interest to the Corps.

<u>SUMMARY</u>: SBEACH has been applied to predict beach change and coastal processes resulting from extreme storm events, both for coastal project design and evaluation, and to synthetically compare beach fill alternatives and storm impacts. Model application may be simplified, using a scoping mode, or constitute a detailed study using design mode. In comparisons with prototype data, SBEACH has been shown to well represent the erosional stages of a storm event for profiles in a cross-shore dominated environment characterized by a non-cohesive sediment of representative grain size. Predictions of recovery (accretion) are qualitative. SBEACH is supported through a structured program at CERC, and model users are encouraged to contact CERC personnel (listed in next section) for assistance with model applications.

<u>AVAILABILITY</u>: SBEACH is available for use on personal computer (PC), and within the Coastal Modeling System (CMS) (Cialone et al. 1991). To obtain the PC version of SBEACH or obtain assistance with model applications, contact Mr. Randy Wise, (601) 634-3085. A description of the CMS is presented in CETN VI-18 (Cialone 1992). For more information about the SBEACH applications to coastal projects discussed herein, please contact the author, Ms. Julie Rosati (601-634-3005) or Mr. Wise, both of the Coastal Processes Branch (CEWES-CR-P).

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